Variability and Sensitivity of GPM-retrieved Mass Weighted Diameter over Italy

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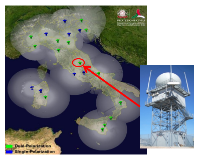
1. Introduction

The retrieval of raindrop size distribution (DSD) from dual frequency precipitation radar (DPR) on board Global Precipitation Measurement (GPM) mission core satellite is one of the key objectives of the NASA's GPM mission. The GPM mission adopted the three-parameter normalized gamma distribution, which includes the mass weighted drop diameter (D_{mass}), normalized intercept and shape parameters. The latest version of the GPM DPR retrieval algorithm relates D_{mass} to the rain intensity R in the form of $R=a \cdot \varepsilon_c \cdot D_{mass}^b$ where an adjustment factor, ε_c, has been introduced to take into account the two-way attenuation path along the radar beam. Two DSD models, for stratifrom and convective precipitations, are used in the DPR retrieval algorithm corresponding to two different R-D_{mass} relationships. The accuracy of D_{mass} retrieval is determined through a comparative study of ground based and space borne products. The Italian Department of Civil Protection (DPC) manages seven C-band polarimetric radars across the all country. This study investigates the validity of DPR derived D_{mass} over Italy through comparative study; applying both the official and the newly developed R-D_{mass} relationships. While the official relationship relies on impact-type Joss-Waldvogel (JW) disdrometer database mostly from tropical sites, the later is based on two-dimensional video disdrometer (2DVD) database mainly from mid-latitude sites.

2. Sites and Instrumentation

This study uses 2DVD observations from six different GPM-GV filed campaigns: Iowa Flooding Studies (IFloodS – 41.6N, 91.5W), Mid-latitude Continental Convective Clouds Experiment (MC3E – 36.7N, 97.1W), Wallops Island, Virginia (Wallops – 37.9N, 75.5W), Huntsville, Alabama (Alabama - 34.7N, 86.6W), Integrated Precipitation and Hydrology Experiment (IPHEx – 35.5N, 82.5W), Olympic Mountain Experiment (OLYMPEx - 47.5N, 123.5W).

This study uses seven C-band radars operated by DPC. All radars have dual-polarization capabilities and the data are generated with 5-minute time resolution, while the azimuthal and range is one degree and 150 m, respectively. It should be noted there are 22 radars over Italy and this is potential for expanded study. The ground radar (GR) data have been matched with both DPR and combined DPR-GMI data.



3. D_{mass} estimation from GR

The ground-based radar retrieval approach adopted here is based on a neural network inversion technique. An artificial neural network is a non-linear parameterized mapping from an input x to an output y=NN(x; w, M) where w=vector of parameters relating the input x to the output y, M=functional form of the mapping (i.e., the architecture of the net). The multi-layer perceptron architecture (MLP), considered here, is a mapping model composed of several layers of parallel processors. The network is trained using supervised learning, with a training set D = (xi, ti) of inputs and targets. During training the weights and biases are iteratively adjusted in order to minimize the so called network performance function, which normally is the sum squared error:

$$E_D = \frac{1}{2}\sum_{i=1}^{N}(t_i - a_i)^2$$

The minimization is based on repeated evaluation of the gradient of the performance function using back-propagation, which involves performing computations backwards through the network

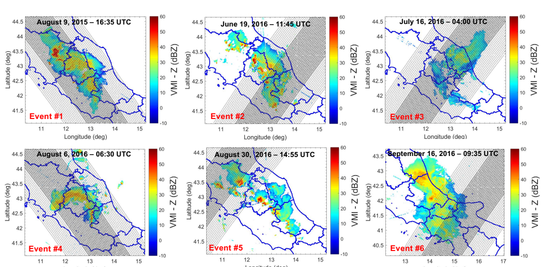
$$\Delta w_{ij} = w_{ij}' - w_{ij} = -\eta_0 \frac{\partial E_D}{\partial w_{ij}}$$

The algorithm has been set up by using simulations of polarimetric radar variables, computed through the T-matrix scattering model, and corresponding rain rates (Vulpiani et al., 2006; Vulpiani et al., 2009). Regarding the microphysical parameterization, the following assumption have been made:

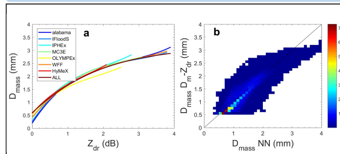
- Axis_ratio: Brandes et al. (2002)
- Temperature: 5<T<20 ° C
- DSD shape: $N(D) = N_w\left(\frac{D}{D_0}\right)^{\mu} e^{-(3.67+\mu)\frac{D}{D_0}}$
- Canting angle: Gaussian distribution with mean=0 deg, std=10deg

4. Case studies

The Vertical Maximum Intensity (VMI) of radar reflectivity had wide variability ranging from largely stratiform rain where reflectivity was less than 35 dBZ to embedded convection where reflectivity exceeded 50 dBZ. All cases had wide areal coverage, which was crucial for the large sample size to compare the DPR derived variables. Given the topography of the region, the *Lowest Beam Map* (**LBM**) of the GR has been spatiotemporally matched with the DPR measurements. The spatiotemporal matching was considered valid only when the DPR individuated the phase of precipitation as liquid. The version 5 (V05) of both DPR and combined DPR-GMI products have been analyzed. A total of 10 case studies have been selected covering the summer season of years 2015-2017 (one case comes from the fall 2016). The figures below report, as examples, six out of the ten considered cases.



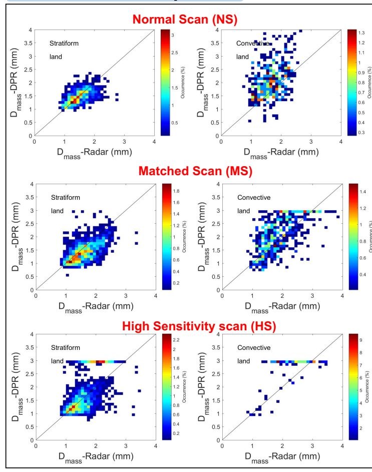
5. D_{mass} NN vs D_{mass} from D_{mass}-Z_{dr} relationship



$$D_{mass} = 0.0193 \cdot Z_{dr}^3 - 0.2564 \cdot Z_{dr}^2 + 1.2925 \cdot Z_{dr} + 0.5920$$

The 2DVD GV data have been used to derive the D_{mass}-Z_{dr} relationship for each field campaign and combining all the field campaigns (Fig a). The derived relationship has been applied to the GR Z_{dr} data estimate D_{mass}. The two approaches (NN and D_{mass}-Z_{dr} show good agreement (Fig. b) especially for lower values of D_{mass}. At higher D_{mass} values the NN estimation is slightly greater than D_{mass}-Z_{dr} approach.

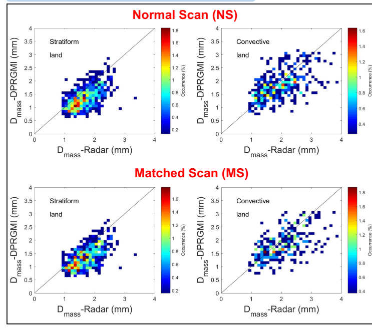
6. 2ADPR-GR comparison



The comparison between the 2ADPR based and GR based D_{mass} shows different results as function of the type of precipitation and DPR scan. Generally, NS and MS have comparable performances and better than HS. MS has better performances for convective precipitation, while HS for stratiform precipitation over sea (not shown).

Both MS and HS show some saturated D_{mass} at 3 mm. The HS for convective precipitation has a very low sample size as well as "Other" category regardless the DPR scan type (for this reason the "Other" is not shown). The same is found for the matching over sea regardless the type of precipitation (see Table in Section 7).

7. 2BCMB-GR comparison



The combined DPR-GMI algorithm shows similar results with respect the DPR. Generally, both NS and MS slightly underestimate D_{mass} for stratiform precipitation, while the agreement with the reference data is better for convective precipitation if compared with 2ADPR products.

As for the 2ADPR products, the samples size of "Other" category as well as the matching over sea for the 2BCMB is very low and it is not shown.

8. D_{mass} Statistics – Absolute Bias & Sample Size

Dmass Absolute Bias (mm)

	DPR-GR						DPRGMI-GR			
	landNS	landMS	landHS	seaNS	seaMS	seaHS	landNS	landMS	seaNS	seaMS
Stratiform	0.21	0.30	0.40	0.35	0.20	0.22	0.38	0.40	0.28	0.27
Convective	0.57	0.45	0.54	0.61	0.61	0.14	0.41	0.43	0.33	0.35
Other	0.12	0.20	0.40	0.10	0.18	0.23	0.32	0.32	0.31	0.29

Sample Size

	DPR-GR						DPRGMI-GR			
	landNS	landMS	landHS	seaNS	seaMS	seaHS	landNS	landMS	seaNS	seaMS
Stratiform	793	1,300	1,892	137	98	261	762	619	231	192
Convective	373	469	95	44	32	10	367	267	32	19
Other	3	29	34	1	10	11	30	26	4	3

The absolute bias in D_{mass} estimation shows good results both for DPR and combined DPR-GMI products. It is generally lower than 0.5 mm, especially over land and for stratiform and convective precipitation, which show a higher sample size. The lower number of samples over sea and for the "Other" precipitation category makes the results less reliable.

For the stratiform precipitation (over land) the DPR outperforms the combined DPR-GMI, while the opposite is true for the convective precipitation.

9. C/S separation

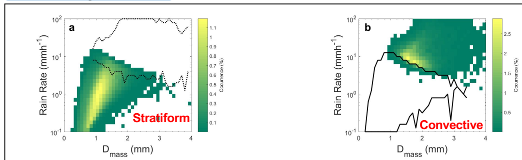
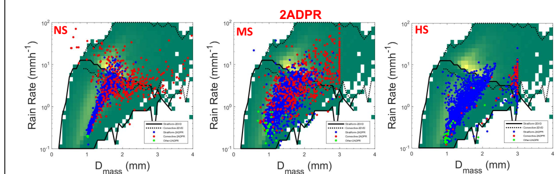


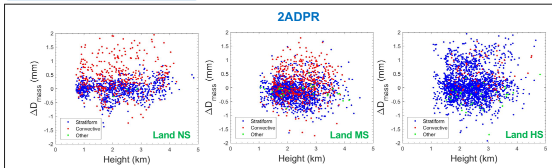
Fig.a Density distribution of the stratiform samples (green area) in R-D_{mass} space by using the 2DVD data and the official C/S separation (Kozu et al., 2009) used the derive the R-D_{mass} relationships. The dashed black line individuates the area of the convective samples.

Fig.b Density distribution of the convective samples (green area) in R-D_{mass} space by using the 2DVD data and the official C/S separation (Kozu et al., 2009) used the derive the R-D_{mass} relationships. The solid black line individuates the area of the convective samples.

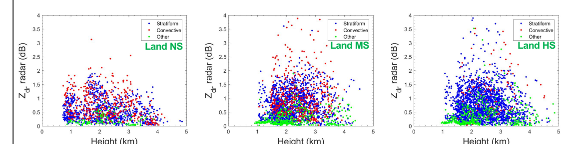


In these three plots, the blue, red and green dots which are, respectively, the stratiform, convective and other R-D_{mass} pairs, as classified by DPR are overlapped to the disdrometer density plots. The DPR uses a different algorithm to categorize the precipitation as stratiform, convective or other. It is evident that the DPR stratiform samples fall in both stratiform and convective regions and vice versa. The Other samples, although they are classified as convective fall in the stratiform region. It seems useless to have a type of C/S separation for the R-D_{mass} constraint and a different type for DPR measurements considering that they do not match.

10. Altitude analysis



The error in estimating D_{mass} has not dependence on the height of the matching point between DPR IFOVs and Radar pixels. This is true for all the precipitation type and for each DPR scan mode, and both over land and over sea (not shown). The same results are also obtained for the combined DPR-GMI products (not shown).



The GR Z_{dr} is uniformly distributed with respect to the height of the matching point between DPR IFOVs and GR pixels. This is true for each DPR scan type over land and for stratiform and convective categories. For the "Other" precipitation type, the corresponding GR Z_{dr} values are generally lower than 0.5 dB regardless the height of the matching point.

11. Conclusions

- A good agreement between GR and DPR and DPR-GMI derived D_{mass} has been found especially for stratiform precipitation over land. The DPR NS and MS have comparable performances, generally better than DPR HS. The combined DPR-GMI generally slightly underestimated D_{mass}, but for convective precipitation shows better results than DPR.
- The error in D_{mass} estimation is generally lower than 0.5 mm for both DPR and DPR-GMI. Furthermore, it does not present any dependence on the altitude of the matching point between GR and DPR.
- The DPR C/S separation does not match with the C/S separation used to derive the R- D_{mass} constraint relationships. This is useless and can produce error in rain rate estimation in case of precipitation type misclassification.
- The error in estimating D_{mass} does not show any marked dependence on the height of the matching point between DPR IFOV and GR pixels.
- The GR Z_{dr} is mostly uniformly distributed with respect to the height of the matching point between DPR IFOV and GR pixels. Most of the GR Z_{dr} values for the "Other" category are lower than 0.5 dB.

References

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